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A STUDY OF DRONE-BASED REALITY CAPTURE FOR CONSTRUCTION MANAGEMENT: KAIZEN IN DAILY HUDDLES

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ABSTRACT

This study explores the application of drone-based reality capture technologies in enhancing Lean Construction practices, particularly through the optimization of daily huddles. While prior studies tend to focus either on drone technology or construction management in isolation, this study integrates both perspectives by developing a practical deployment workflow and a set of reality capture tools tailored to typical stakeholder activities. A set of Lean-aligned evaluation metrics was designed to assess performance quantitatively. The proposed approach was implemented and tested in two real-world construction projects in Southeast Asia—one in Thailand and one in Singapore—representing the first time these project teams adopted drone-based workflows. Quantitative results demonstrate improvements in productivity, waste reduction, Just-in-Time execution, and stakeholder collaboration. The findings suggest that drone-based reality capture solutions, when strategically integrated with existing workflows, can significantly support Lean objectives.

KEYWORDS

Lean construction, UAV, Reality Capture, Daily Huddle, Kaizen

INTRODUCTION

Construction project management remains a critical yet challenging task in modern practice. Traditional methods such as Gemba walks, manual inspections, and extensive documentation are still widely adopted (Kumar et al., 2015). While these methods provide a certain level of control, they are often inefficient, inaccurate, and resource-intensive (Amusan et al., 2021; Nikmehr et al., 2021). Based on observations across multiple projects within the author's corporation, one of the key underlying issues is the lack of effective and timely information flow between the back-office management teams (including departments such as design and quality control) and the on-site construction teams. This communication bottleneck poses significant challenges to the advancement of Lean Construction principles, particularly in terms of waste reduction, Just-in-Time (JIT) execution, and Kaizen for workflow and collaboration.

To address this challenge, the author's corporation has attempted to leverage Building Information Modeling (BIM) solutions. These are widely regarded as platforms equipped with effective tools for supporting construction management techniques and for overseeing the "four bottom lines" of project performance—schedule, cost, quality, and safety (Parsamehr et al.,

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2023). However, after deploying BIM-based platforms across multiple sites in the author's corporation, it became evident that BIM alone still struggles to bridge the gap between back-office resources and site-level execution. Despite the abundance of rich BIM resources—such as drawings, 3D models, detailed object metadata, and even 4D/5D dimensions—produced by BIM teams, these resources remain underutilized at the construction site. The same challenge applies to the back-office management resources: the management team's human capital, managerial expertise, and accumulated experience are not being efficiently transferred to the front-line workers. This disconnect indicates a need for additional technological solutions that support more seamless back-to-field information integration and delivery.

Among mainstream approaches to tackling this issue, one strategy is to project back-office resources into the field using immersive technologies such as Augmented Reality (AR), Virtual Reality (VR), or Mixed Reality (MR) devices (Chong & Kim, 2024; Jo et al., 2021). While promising in theory, this approach is currently limited by hardware maturity.

An alternative strategy focuses on enabling a reverse flow of information: capturing physical site conditions and reconstructing them digitally to support remote construction management. This approach—commonly referred to as reality capture—lies at the heart of this study (Elliott & Olbina, 2023). Technologically, there are several viable pathways to implement reality capture solutions. Each path offers a different balance of performance across various KPIs, such as precision, data collection frequency, cost, and scalability (Capolupo, 2021; Keitanniemi et al., 2021; Alexiou et al., 2021). Table 1 presents a comparison of the three mainstream reality capture technologies currently under research and development at the author's corporation.

Table 1: Comparison of Mainstream Commercial Technologies for Reality Capture

KPI	Terrestrial Laser Scanning (TLS)	Mobile Laser Scanning, MLS / SLAM-based LiDAR	2D Photogrammetry Based 3D Generation, Structure-from-Motion (SfM)
Precision	High, millimeter level	Medium, millimeter to centimeter level (hardware-dependent)	Low, centimeter-level (depends on hardware, algorithm, and GCP setup)
Data Collection Frequency	Low (complex setup)	High (flexible and rapid deployment)	High (flexible and rapid deployment)
Cost	High (expensive equipment and skilled labor required)	Medium to high (cheaper than TLS but still costly)	Low (commercial camera + software only)
Ease of Use	Low (requires professional training)	Medium (SLAM setup required)	High (intuitive operation)
Scalability	Suitable for small areas requiring high precision	Flexible deployment in large areas	High; able to cover large areas
Data Processing Complexity	High (point cloud registration and stitching needed)	Medium (attention required to manage SLAM errors)	Low to medium (semi-automated processing)
Proposed Scenarios	Highest accuracy, ideal for detailed quality control	Flexible and mobile, suitable for daily monitoring of large sites	Low-cost option for frequent site updates via drones, handheld 360° cameras, etc.

From this comparison, it becomes evident that for most ordinary construction projects operating under constrained budgets, the photogrammetry-based 3D generation (SfM) technology using conventional optical cameras presents a highly attractive and practical solution. This method offers low-cost implementation while maintaining high-frequency and flexible reality capture—attributes that are particularly valuable for enhancing the situational awareness of back-office teams, and a good situational awareness is the cornerstone to achieve those Lean construction objectives mentioned earlier.

Regarding the data capture platform, unmanned aerial vehicles (UAVs or drones) were selected as the primary focus of this study, to verify whether and how much it is capable of helping the site activity. Drones offer a unique advantage: the ability to quickly capture comprehensive, bird's-eye views of construction sites—including areas that are typically difficult or dangerous to access, such as rooftops or elevated structures (Nex & Remondino, 2014). Additionally, the integration of drone-captured data with Building Information Modeling (BIM) systems has demonstrated proven benefits in areas such as progress tracking and predictive analytics (Tuhaise et al., 2023).

Finally, in order to quantitatively assess whether drone-based reality capture meaningfully supports construction project teams—and to what extent—it is essential to anchor the investigation within a core activity of Lean Construction. For this purpose, the daily huddle was selected as the focal point of observation. As a fundamental component of Lean practice, the daily huddle provides a structured setting where situational awareness, workflow coordination, and continuous kaizen converge. By using this activity as the lens through which drone-based technologies are evaluated, this study aims to generate findings that are both actionable and broadly applicable, and intends to offer practical insights and strategic guidance for industry practitioners, policymakers, and researchers who are committed to advancing Lean Construction.

METHODS

This study begins by reviewing the current landscape of literature concerning drone-based reality capture for construction management, followed by introducing the detailed deployment workflow and a set of reality capture tools, which are proposed to enhance the daily huddle—a key Lean Construction activity—along with their corresponding stakeholder roles and related tasks. Then, a set of evaluation metrics is proposed to support quantitative analysis.

LITERATURE REVIEW

When discussing drone-based reality capture for construction management, existing research typically tends to emphasize either the drone technology aspect or the construction management aspect, but rarely both aspects in equal measure.

Studies that lean toward construction project management often focus on the practical applications and use cases of drone technologies, such as land surveying, logistics coordination, on-site inspections, progress monitoring, and occupational health and safety assessments. These studies highlight the potential benefits of drone use—including increased productivity, early detection of deviations, improved worksite safety, cost-effectiveness, and even reductions in carbon emissions—as well as challenges and risks, such as legal liabilities, crash-related injuries, and privacy violations (Yıldız et al., 2021; Li & Liu, 2018). However, such contributions are predominantly qualitative in nature, based on literature review or case studies, and tend to lack quantitative validation through true data collection and analysis.

On the other hand, studies that focus on drone-based reality capture are largely centered around technical components (e.g., aerial imaging methods, 3D reconstruction algorithms) or function-specific implementations (e.g., volume calculation, integration with BIM or GPS systems). Many such works are dedicated to specialized applications unrelated to the construction industry—for example, using UAV photogrammetry to estimate millimeter-scale surface roughness of rock outcrops (Nakamura et al., 2024).

This paper aims to address this gap by proposing a stronger integration between drone-based reality capture technologies and construction management processes, particularly within the context of Lean Construction. The study explores how commercially available drone-based solutions can be strategically deployed to support a representative Lean task—the daily huddle—and evaluates their impact through quantitative data analysis. In doing so, the paper seeks to provide both theoretical insights and practical benchmarks for researchers, industry practitioners, and policymakers interested in advancing digital tools for Lean Construction.

DRONE-BASED REALITY CAPTURE SOLUTION DEPLOYMENT WORKFLOW

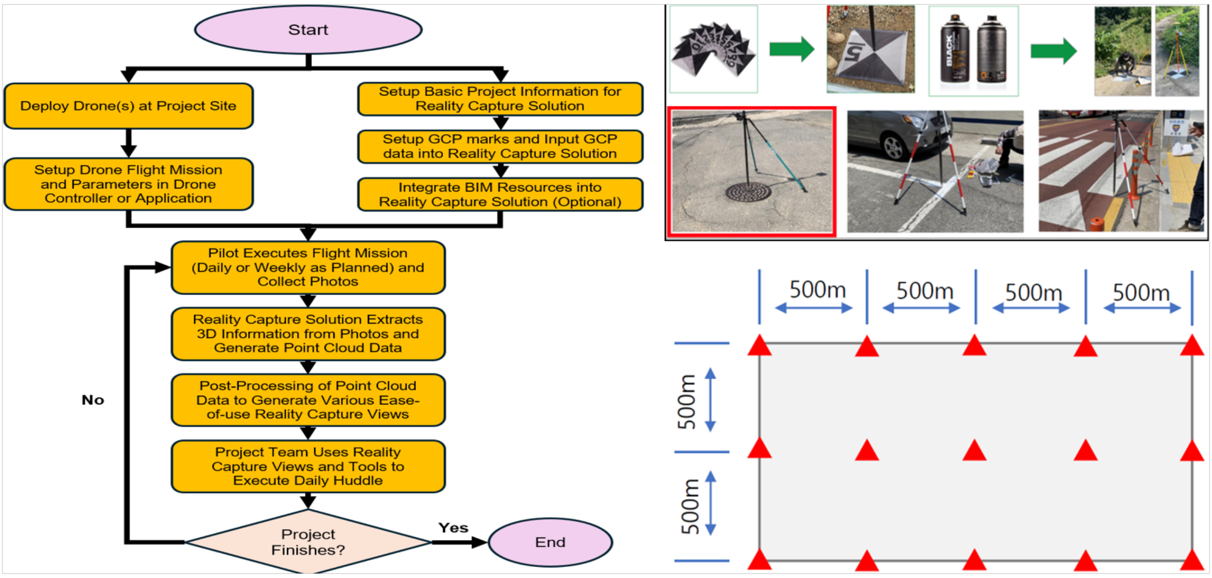

Figure 1: Deployment Workflow (Left), Examples of Artificial GCP Marks and Virtual GCP Marks (Top Right), and Example of Proposed GCP Mark Layout (Bottom Right)

The workflow presented in Figure 1 outlines the key steps involved in the proposed method. To provide a clearer understanding of some of the steps which may easily cause confusion, a detailed explanation is given below.

- 'Deploy drones at project site' involves using high-resolution optical cameras on drones to capture construction site photos. Since the point cloud data is extracted from the 2D high-resolution photos taken by the drone's camera, a drone equipped with a camera that has at least 20MP effective pixels is strongly recommended.
- 'Setup Flight Mission and Parameters in Drone Controller or Application' is strongly recommended to be carried out on a drone with automatic flight mode and automatic photo shooting mode, as such works are quite challenging to the pilot if it is done manually. The purpose of implementing drone-based solutions is to enhance lean construction and productivity, not the other way around. 'Setup GCP marks and Input GCP data into Reality Capture Solution' is an important step. Ground Control Point (GCP) refers to a reference point with known three-dimensional coordinates (longitude, latitude, elevation) set on the surface of the earth, which is used for calibration and georeferencing of geospatial data. 'GCP marks' are artificial or natural reference points set on the ground with corresponding coordinate values, usually at the corners and along the edge of the site. More GCP marks may be set inside the site as well in case the site area is large. The GCP marks should be placed in locations free of overhead obstacles and less susceptible to loss, ensuring their visibility in drone imagery. The GCP coordinates were to be measured and provided by surveyors.

- When stitching 2D photos and generating 3D point clouds, errors may accumulate in the multi-view reconstruction process. GCP marks act as fixed anchors to minimize error propagation. By installing or defining GCP marks on site before drone flight, the distortion and deformation of generated point cloud data will be minimized, thus the accuracy of reality capture is improved. Based on the experience gained from the author's corporation, the precision of reality capture with well-set GCP marks can be up to 1~10cm, while the precision without GCP marks may vary between 1~100cm and may be even worse at the boundaries due to reduced overlapping and accumulated errors.
- 'Reality Capture Solution Extract 3D information from photos and generate point cloud data' refers to SfM method (Turner et al., 2012) in this study.
- 'Post-Processing of Point Cloud to Generate Ease-of-use Reality Capture Views' involves the process of using visualization techniques to generate 2D views and 3D views which are user-friendly, such as mesh modeling (Tuhaise et al., 2023), Gaussian Splatting (Fei et al., 2024), Voxel Rendering (Xu et al., 2021), etc. Advanced 2D or 3D views can also be generated for specific tasks, such as the terrain view (Zeybek & Şanlıoğlu, 2019). Post-Processing is a particularly critical step, as it largely determines the level of visual output presented to the stakeholders. High-quality visualizations are more likely to gain stakeholders' acceptance and foster trust in the proposed solution.

With the key steps successfully implemented, the reality capture solution is now ready for the construction project team's usage.

KAIZEN IN DAILY HUDDLES

Table 2 illustrates some of the main stakeholder tasks in daily huddles and how reality capture tools can help optimize these tasks. Reality capture helps ensure that each participant has access to up-to-date, actionable insights to reduce waste, improve productivity, assist JIT execution, and finally achieve the kaizen in daily huddle workflow.

Table 2: Proposed Reality Capture Tools as Enhancement to the Conventional Methods for Stakeholder Tasks in Daily Huddles

Stakeholder and Task	Conventional Method	Proposed Reality Capture Tool as Enhancement
Project Manager: Progress management	Gemba walk or via reports, photos and Kanban, etc.	Reality capture views with historical records
Project Manager: Construction Accordance with Designs	Gemba walk, request surveyor team to measure or via reports and photos, etc.	Reality capture views with measurement tools and BIM integration
Project Manager: Quality Issue Management	Gemba walk or via reports, photos, Kanban, and software tools, etc.	Reality capture views with mark-up tools and issue management tool
Site Engineer: Task or Resource Allocation (Manpower, Equipment, Materials)	Oral or written instructions, via Kanban, etc.	Reality capture views with mark-up tools and 3D object tool
Site Engineer: Dimension Accordance with Designs	Gemba walk, request surveyor team to measure or via reports and photos, etc.	Reality capture views with measurement tools and BIM integration

Table 2 continued: Proposed Reality Capture Tools as Enhancement to the Conventional Methods for Stakeholder Tasks in Daily Huddles

Stakeholder and Task	Conventional Method	Proposed Reality Capture Tool as Enhancement
Site Engineer: Quality Issue Creation and Follow-up	Gemba walk or via reports, photos, Kanban, and software tools, etc.	Reality capture views with mark-up tool and issue management tool
Safety Officer: Lean 5S Monitoring	Gemba walk and fixed-camera view	Reality capture views with historical records
Safety Officer: Hazardous Zones Tagging and Monitoring	Tagging on drawings, static maps, and photos; monitoring by gemba walk and fixed-camera view	Reality capture views with mark-up tool, 3D object tool, measurement tools, and historical records
Quality Control: Quality Issue Creation and Follow-up	Gemba walk or via reports, photos, Kanban, and software tools, etc.	Reality capture views with mark-up tool and issue management tool
Quality Control: Outdoor Material Storage Management	Gemba walk, fixed camera view, via reports, photos and Kanban, etc.	Reality capture views with mark-up tool and measurement tools and historical records

METRICS FOR QUANTITATIVE ANALYSIS

In this study, a set of evaluation metrics was designed to align with the key principles commonly associated with Lean Construction, as shown in Table 3. While efforts have been made to conduct quantitative analysis wherever possible, the availability of measurable data types has been limited by time and resource constraints.

Table 3: Metrics Designed to Evaluate Lean Construction Performance in Daily Huddles

Key Performance Indicators (KPI)	Impacted Activity	Calculation Method
Reduced waste: manhour saved for each relevant stakeholder	Gemba walk Giving instructions, including creating Kanban Content	Productivity Improvement (%) = Saved manhour / Total manhour
Reduced waste: manhour saved for surveyor's team (downstream task of daily huddle)	Surveyor's measurement activities	Productivity Improvement (%) = Saved manhour / Total manhour
Just-in-time: reality capture utilized days	Outdoor Material Storage Management on a daily basis	Reality Capture Utilization Rate (%) = Number of Utilized Days / Number of Total Working Days
Kaizen in communication and collaboration	Daily huddles	Reality Capture Utilization Rate (%) = Number of Utilized Days / Total Number of Daily Huddles

RESULTS

This section presents data collected from the drone-based reality capture solution and its integration with daily huddle, as observed in two construction projects conducted by the author's corporation. A quantitative analysis is then executed based on the predefined metrics.

CASE STUDIES

The two case studies were conducted in Thailand and Singapore, respectively. It was the first time for both project teams to experience such a drone-based reality capture solution. The key project details and deployment parameters are summarized in Table 4.

Table 4: Case Study Information and Solution Deployment Parameters

Items	Case Study 1	Case Study 2
Project Location	Bangkok, Thailand Far from city and airport	Singapore, Singapore In city (a few airports in city)
Project Time	Year 2023 - 2024	Year 2024 - 2025
Project Scale	Site area around 35,000 m^2	Site area around 75,000 m^2
Drone Operator	Qualified site engineer	Qualified local vendor
Drone Model	DJI MAVIC 3 Enterprise	DJI Mavic 3 Classic
Drone Camera	4/3 CMOS Effective Pixels 20 MP	
Photo Capture	Equal time interval, 80% overlap ratio	
Drone Flight Frequency	Daily (unless cancelled due to bad weather or pilot absence)	Weekly (Less frequently due to Singapore regulatory reasons)
Drone Solution Adopted Period	203 working days	48 working weeks (240 working days)
Drone Flight Implemented	122 flights = 122 reality captures (Covered 60% working days)	46 flights = 46 reality captures (Covered 96% working weeks)
Flight Time	5~10 minutes per task	20~25 minutes per task
Flight Altitude	100 m (RTH)	65 m (RTH)
Photos Collected	200~300 photos per task	400~500 photos per task
Photo Processing time	4~8 hours required to generate the reality capture after the photos are uploaded to the cloud platform	
Daily Huddle Members	Project manager x1; site engineers x1; quality control manager x1; safety officer x1	Project manager x2; site engineers x2; quality control manager x1; safety officer x1
Measurement Executed in Reality Capture	167 times (GCP 25 times, location 17 times, distance 54 times, area 29 times, volume 42 times)	304 times (GCP 1 time, location 2 times, distance 99 times, area 92 times, volume 110 times)
BIM Resource Integrated	3 PDF drawings; 2 CAD drawings; 1 IFC model	1 CAD drawing; 2 IFC models

It is important to note that the research team proposed and planned to conduct daily data collection and reality capture updates for both projects, in order to obtain the maximum benefit of drone solution. However, due to Singapore's strict drone operation regulations, even with the assistance of a qualified professional vendor, the project team was only able to secure weekly drone flights.

In addition, the Singapore vendor utilized a non-automated drone model (DJI Mavic 3 Classic) to save hardware costs and relied heavily on the personal skill and experience of the pilot. Such an approach is not recommended as it adds operational risk and increases the reliance on individual operator skills, and further contradicts the principles of Lean Construction, which advocate for automation, standardization, and intelligent processes.

The following Table 5 presents the quantitative analysis based on the metrics designed to evaluate Lean Construction KPIs. Due to space limitations, a large amount of raw data collected through site observations, stakeholder interviews, and backend logs from drone-based reality capture commercial solution platform will not be elaborated here, as well as the detailed calculation processes.

Table 5: Evaluation of Digital Twin Solutions Adopted to Some Stakeholder's Typical Tasks in a Daily Huddle in Thailand Project

KPI	Stake-holder	Case Study 1 Analysis	Case Study 2 Analysis
Reduced Waste: Manhour saved for Gemba Walk (Productivity Improvement % = Saved manhour / Total manhour)	Project Manager	Productivity Improvement 3.4% = 60.9 hour / 1786.4 hour	Productivity Improvement 4.5% = 96 hour / 2112 hour
	Site Engineer	Productivity Improvement 2.8% = 50.75 hour / 1786.4 hour	Improvement 2.8% = 60 hour / 2112 hour
	Safety Officer	Productivity Improvement 3.8% = 67 hour / 1786.4 hour	Productivity Improvement 5.7% = 120 hour / 2112 hour
	Quality Control	Productivity Improvement 2.8% = 50.75 hour / 1786.4 hour	Productivity Improvement 5.7% = 120 hour / 2112 hour
Reduced Waste: Manhour Saved for Giving Instructions	Site Engineer	Productivity Improvement 1.9% = 34.5 hour / 1786.4 hour	Productivity Improvement 2.3% = 48 hour / 2112 hour
Reduced waste: manhour saved for surveyor's team	Surveyor	Vendor, Productivity Improvement 14% = 250.5 hour / 1786.4 hour	Site Team, Productivity Improvement 14.4% = 304 hour / 2112 hour
Just-in-time: reality capture utilized days	QC	Reality Capture Utilization Rate 6.4% = 13 days / 203 days	Reality Capture Utilization Rate 12.1% = 29 days / 240 days
Kaizen in Communication and Collaboration	All	Reality Capture Utilization Rate 40.4% = 82 daily huddles / 203 daily huddles	Reality Capture Utilization Rate 39.6% = 95 daily huddles / 240 daily huddles

The quantitative analysis results indicate that the drone-based reality capture solution effectively contributes to Lean Construction objectives. Focusing on individual indicators, Gemba Walk productivity showed consistent improvement across stakeholder roles, typically ranging between 2% to 5%.

For site engineers, the manhours saved on 'giving instruction to front-line workers' was even slightly less, as the saved manhours were mainly due to using screenshots to replace hand-drawn sketches and drafts.

Notably, although surveyors are not direct participants in the daily huddle, they often act as downstream task executors following stakeholder demands of measurement. The reality capture solution significantly reduced manhour expenditure for this group, making it one of the largest contributors to overall time savings related to daily huddle outcomes.

Regarding the Just-in-Time indicator, due to the complexity of quantifying this KPI, the study used the Reality Capture Utilization Rate as a proxy to reflect how often QC teams employed reality capture tools as part of their workflows. The data shows that while the

Singapore team achieved a higher utilization rate than the Thailand team, both case studies still demonstrate ample room for further improvement.

As for Kaizen in communication and collaboration, both case studies showed a utilization rate of around 40%, which—although not particularly high—can still be seen as a promising start for teams using the solution for the first time. This initial adoption phase indicates that while the technology has already gained recognition, broader adoption will likely require more time and hands-on experience to build familiarity and trust.

DISCUSSION

VALUE OF DRONE-BASED REALITY CAPTURE SOLUTIONS

Based on the quantitative evaluation of Lean Construction KPIs, drone-based reality capture solutions clearly demonstrate their unique value in improving transparency and situational awareness. However, whether such a solution is worthy of deployment should be weighed against cost-effectiveness, which mainly depends on regional labour costs and project demands.

According to the author’s corporation's experience, deploying a drone-based solution typically incurs a relatively fixed cost, which may range from USD 10,000 ~ 20,000 per year per project regardless of the regions. Therefore, projects in regions with high labour costs, limited technical workforce, or larger, more complex sites are especially well-positioned to benefit from this type of solution.

CHALLENGES AND SOLUTION EXPLORATION

Regarding stakeholder adoption and integration with existing workflows, based on the interview results, all stakeholders expressed their willingness to accept this solution in the workflow as it provides convenience without causing additional workload or major impact on existing workflows. Except for some monetary costs for the project, it is almost all net benefit for stakeholders, albeit to varying degrees. This can be reflected in the fact that stakeholders used measurement tools extensively in both case studies (167 and 304 times).

In addition, the quantitative analysis also shows the stakeholder resistance. Although both projects used drone-based solutions for the first time, the Singapore team’s weekly reality capture plan could achieve a performance comparable to that of the Thailand team’s daily plan because the Singapore team was more accustomed to using digital tools. This provides a possible direction for eliminating stakeholder resistance, that is, frequent usage to increase familiarity with digital tools as well as the ability to gain benefits from them.

Regarding data accuracy, currently the centimeter-level accuracy can only achieve project Overview-level management, and the measurement tools are only applicable to works with low accuracy needs, such as soil excavation, backfilling, and outdoor material storage management, etc. However, this problem is being solved naturally by the development of optical hardware and 2D-to-3D software technology. Mainstream drone cameras may have significant improvement around every 5 years (e.g. Phantom 3 versus MAVIC 3 Enterprise), and various 2D-to-3D technologies based on machine learning and AI algorithms have made rapid progress in the past 2~3 years. Under optimistic assumptions, the accuracy of drone-based reality capture solutions may reach sub-centimeter level (<10mm) in the next 3~5 years, which would make them even more viable for precision-oriented use cases. As for now, if a project has an immediate demand for higher accuracy of drone-based reality capture, there is still a solution to replace optical cameras with LiDAR on the premise of appropriately increasing the budget.

LIMITATIONS AND FURTHER STUDY

Several limitations were identified during the course of this study. First, the two case studies were relatively favorable for the implementation of drone-based solutions. Both projects involved low-rise structures with not so complicated architectural and MEP systems—the majority of the work was concentrated on infrastructure and structural phases, where the drone-based solutions may offer the greatest value. Future research should include projects with different typologies, particularly multi-story buildings with more complex architectural and MEP systems. Of course, it should be noted that not all high buildings will weaken the performance of drone-based solutions. For example, aesthetic-focused buildings with elaborate façades or complicated superstructure design may offer even greater opportunities for drone-based solutions to demonstrate their potential.

Another limitation relates to the applicability of drone-based solutions across different construction phases. At present, drones are most effective in capturing external environments, making them especially useful during the infrastructure and structural construction phases. Their value diminishes in later phases, such as interior fit-out and MEP installation, where much of the work occurs indoors and is inaccessible to drones. The analysis in this study is based on the average performance across the full project timeline and does not account for performance variation across different phases. Future studies should examine drone solution performance in a phase-specific manner to provide more detailed and targeted insights.

Finally, there are limitations regarding data accuracy and calculation methods. Due to time and manpower constraints, some calculations were based on standard estimation rules used in the author's corporation rather than direct data collected from site teams. A typical example is the total manhour values per stakeholder, which were derived using planning rules instead of actual recorded hours. In future work, the research team aims to improve data collection strategies and allocate more resources to gather first-hand site data, enabling more precise and reliable quantitative analysis.

CONCLUSIONS

This study proposes and validates a drone-based reality capture workflow tailored to support Lean Construction through the enhancement of daily huddle activities. By developing a structured toolset and evaluating its impact using quantitative metrics, the study reveals meaningful improvements in stakeholder productivity, time savings, and communication efficiency. Notably, the integration of these tools proved especially valuable in streamlining downstream tasks such as measurement and reporting, which are often time-consuming in conventional workflows.

One of the key contributions of this research lies in the use of first-hand case study data gathered from two actual construction projects in Southeast Asia. These cases not only validate the practical feasibility of the proposed solution, but also highlight contextual challenges such as regulatory constraints, team digital maturity, and project typology. The comparative insights derived from daily vs. weekly drone deployment models further enrich the discussion around cost-effectiveness and scalability.

While the study demonstrates the value of drone-based reality capture in supporting Lean KPIs such as waste reduction and Kaizen, it also acknowledges limitations related to data collection, project typology, and construction phase applicability. Future research should explore multi-phase implementations across more complex building types, and leverage finer-grained site data to strengthen the reliability of impact assessment.

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